Evaluation of sounder composition products

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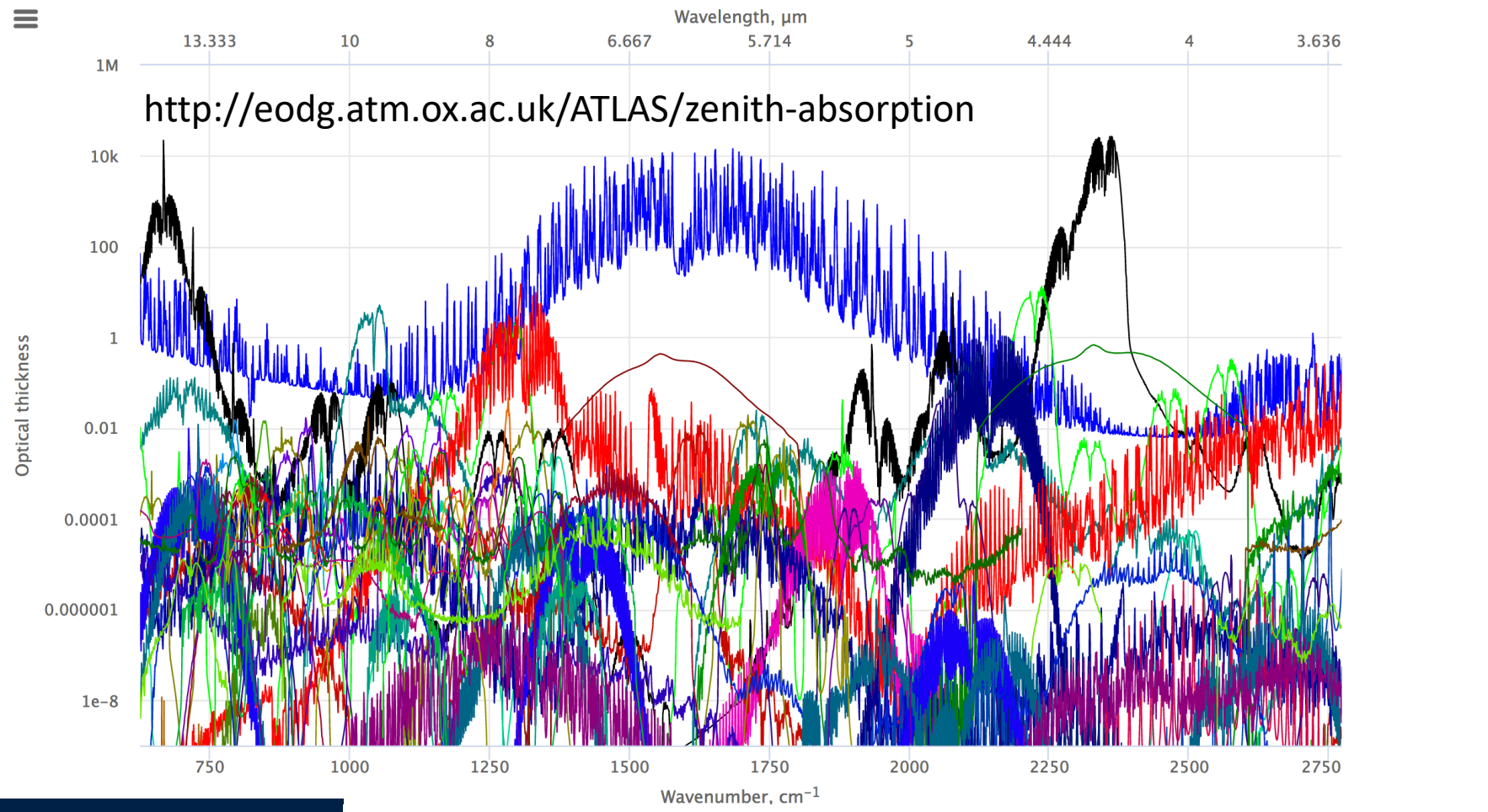
IR sounders offer a wealth of information on atmospheric composition that can be used to advance Earth System Science.



EODG
Earth Observation Data Group
Atmospheric Infrared Spectrum Atlas

The Earth System is complicated….

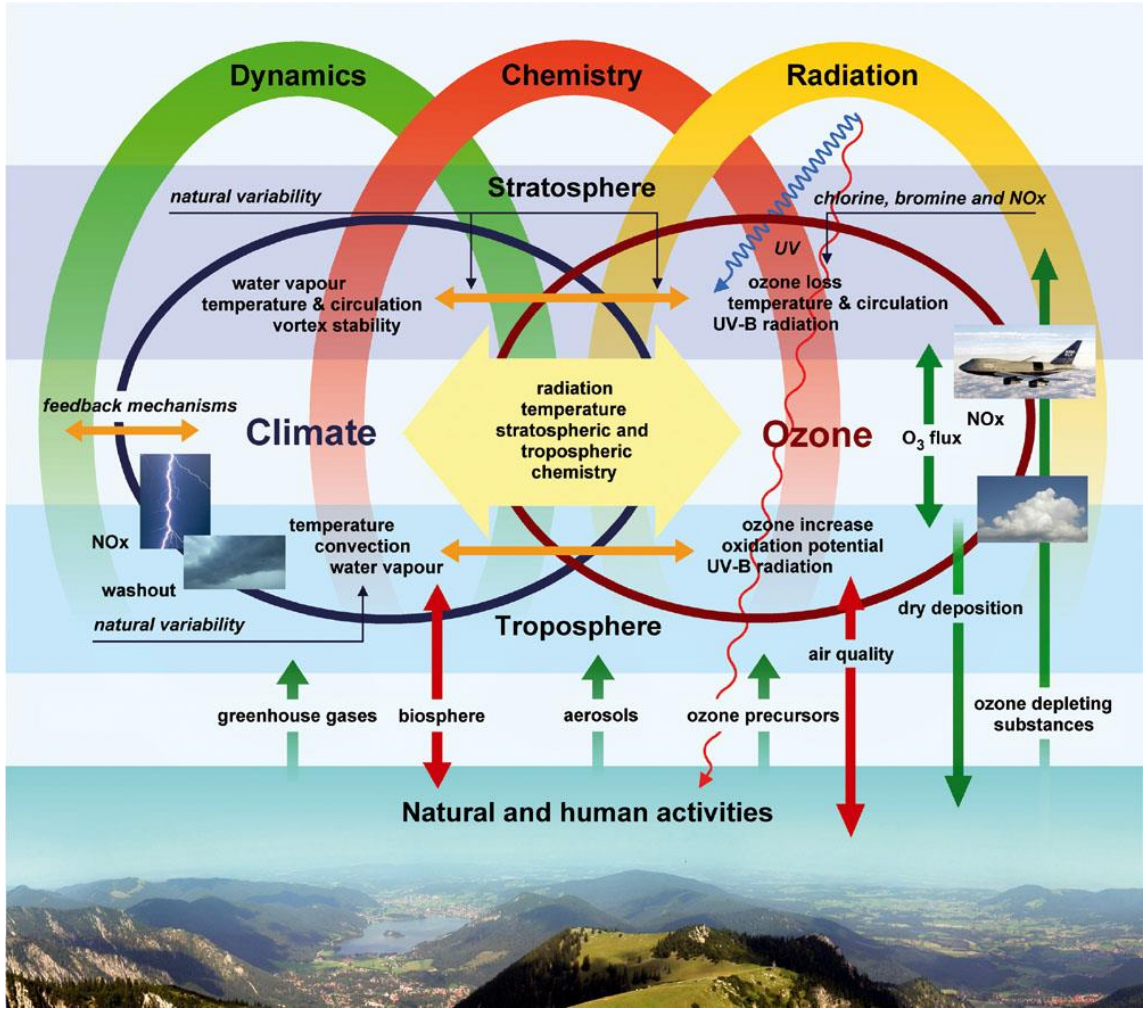


Image: DLR, after WMO-IGACO

“Townspeople, who have never seen an elephant, examine its appearance in the dark.”
Image: Walters Art Museum

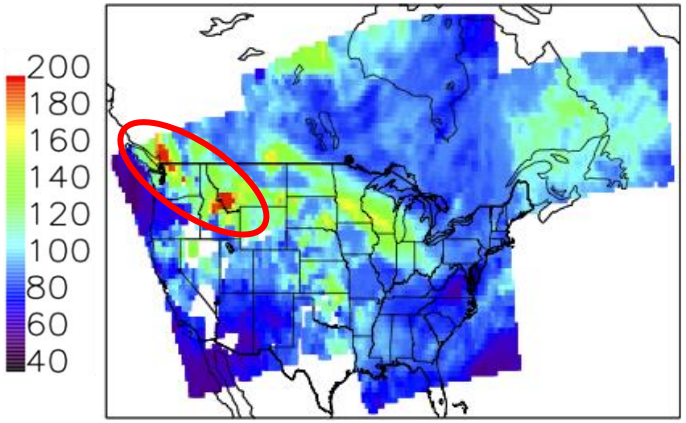
No one measurement technique can provide all the answers

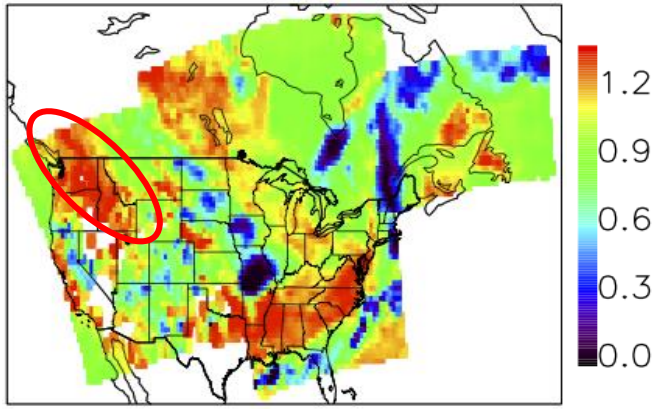
- **The biggest scientific gains are to be had not from analysis of sounder products alone, but from utilization of sounder products in context of other datasets and modeling and/or chemical data assimilation.**
- This requires:
  - Observation operators (e.g. averaging kernels)
  - Realistic uncertainty estimates
    - Calculate as part of the retrieval, evaluate using independent reference datasets
- These vary according to:
  - Atmospheric conditions (e.g. temperature, humidity, cloud)
  - Surface conditions (e.g. thermal contrast, surface emissivity)

Sensitivity and errors vary by location/conditions

Example: CrIS CO retrievals from MUSES (D. Fu)

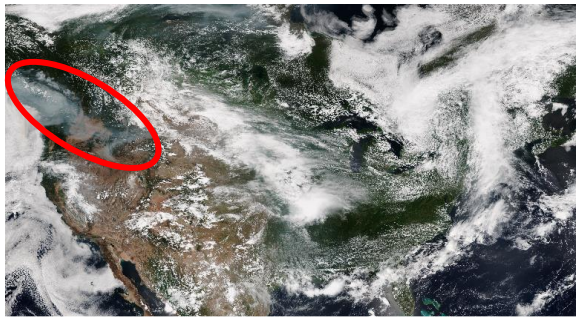
CO VMR
@510 mbar
ppb

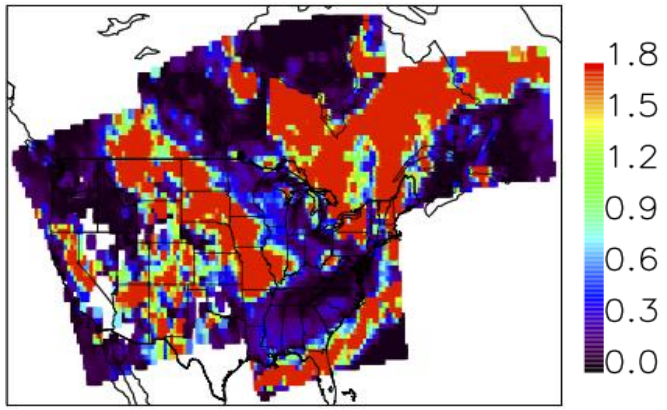




CrIS Trop.
CO DOFS

MODIS
Image





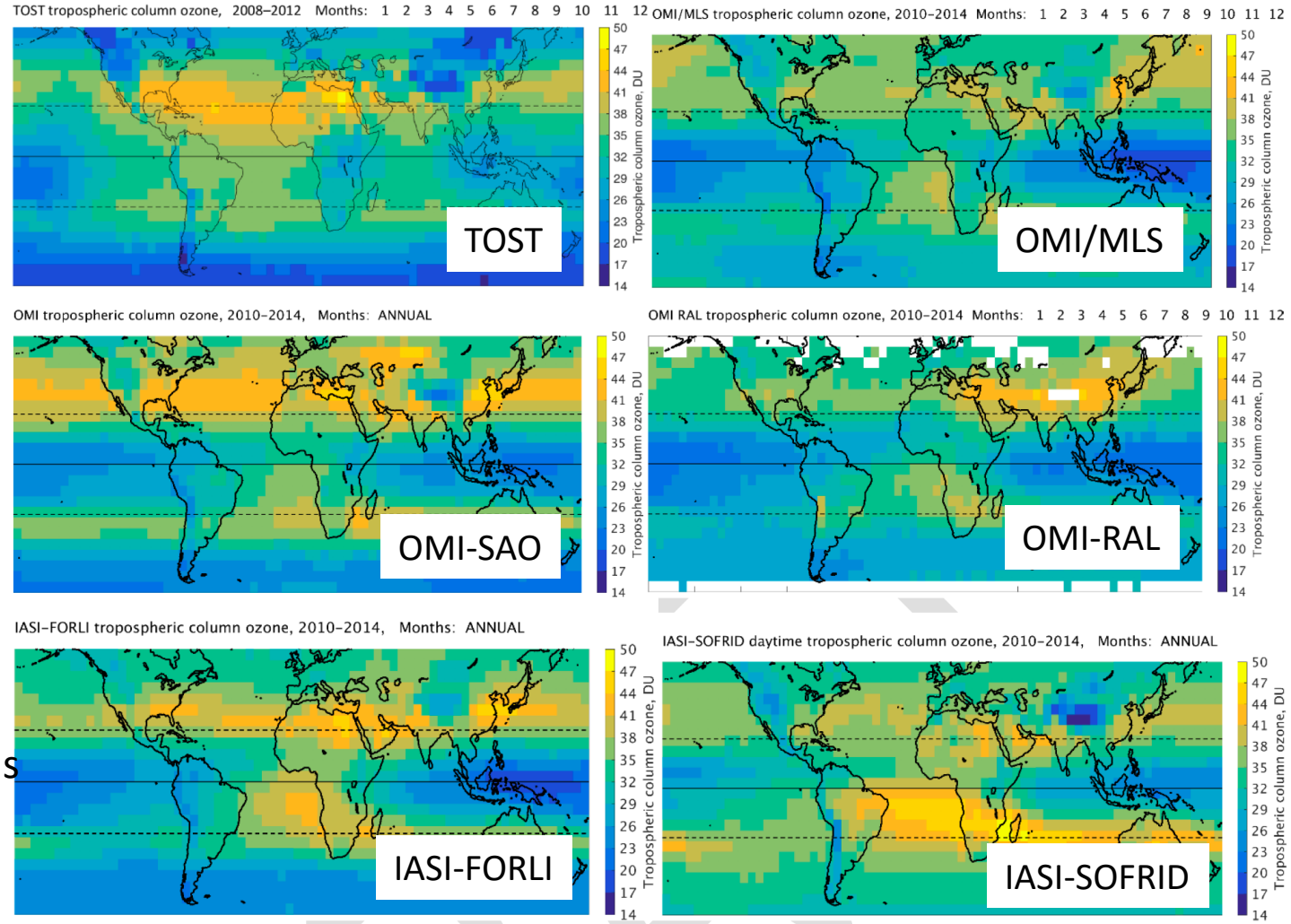
CrIS Cloud
OD

Evaluation of composition products

- Possible sources of information for reference/comparisons
  - Model output (sanity check)
  - Other relevant satellite datasets
  - Long-term/ongoing ”reference” datasets
  - Campaign datasets

- Other related perspectives on product evaluation
  - Nalli et al., JGR, 2013, Nalli et al., Fall 2017 NSSTM
    - “Validation Hierarchy” for SNPP/JPSS Cal/Val
  - Bjorn’s talk this afternoon

Comparing satellite datasets (ozone example)



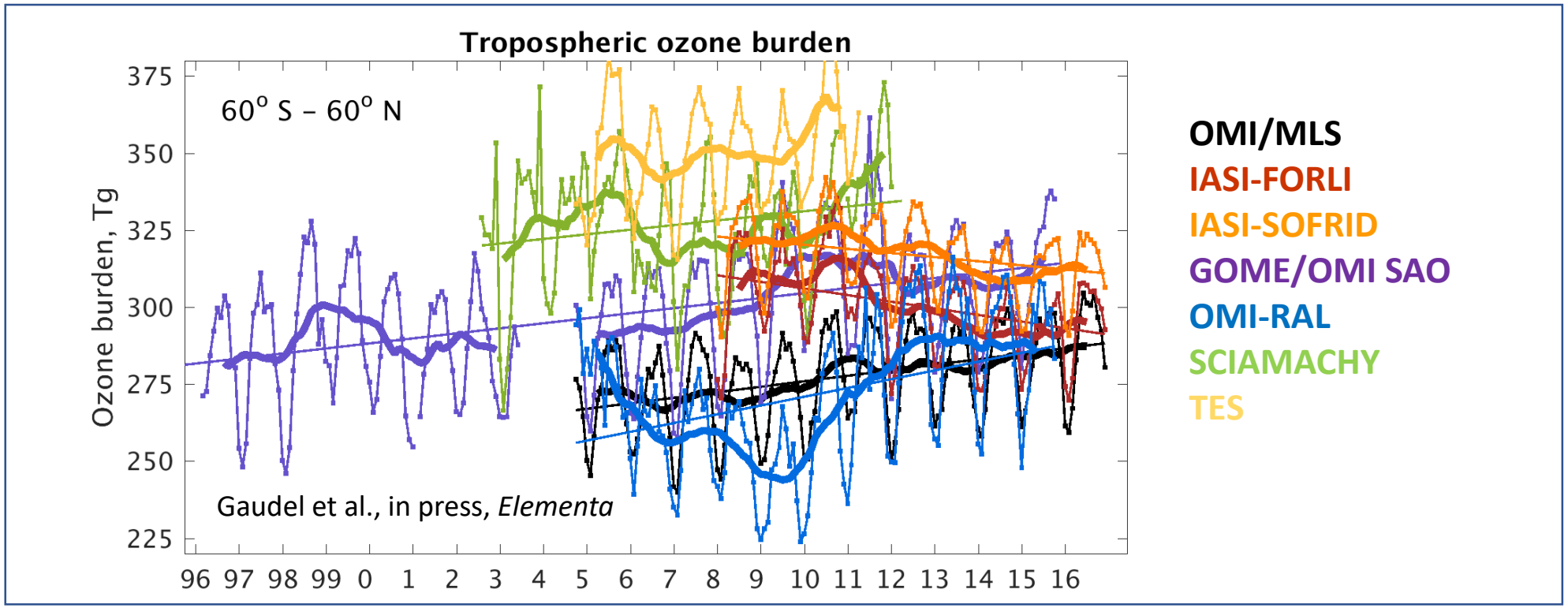
Annual mean tropospheric column ozone Gaudel et al., in press, Elementa

TOAR
Tropospheric Ozone Assessment Report

IGAC activity
(IGAC = International Global Atmospheric Chemistry)

TOAR Mission:
"To provide the research community with an up-to-date scientific assessment of tropospheric ozone's global distribution and trends from the surface to the tropopause."

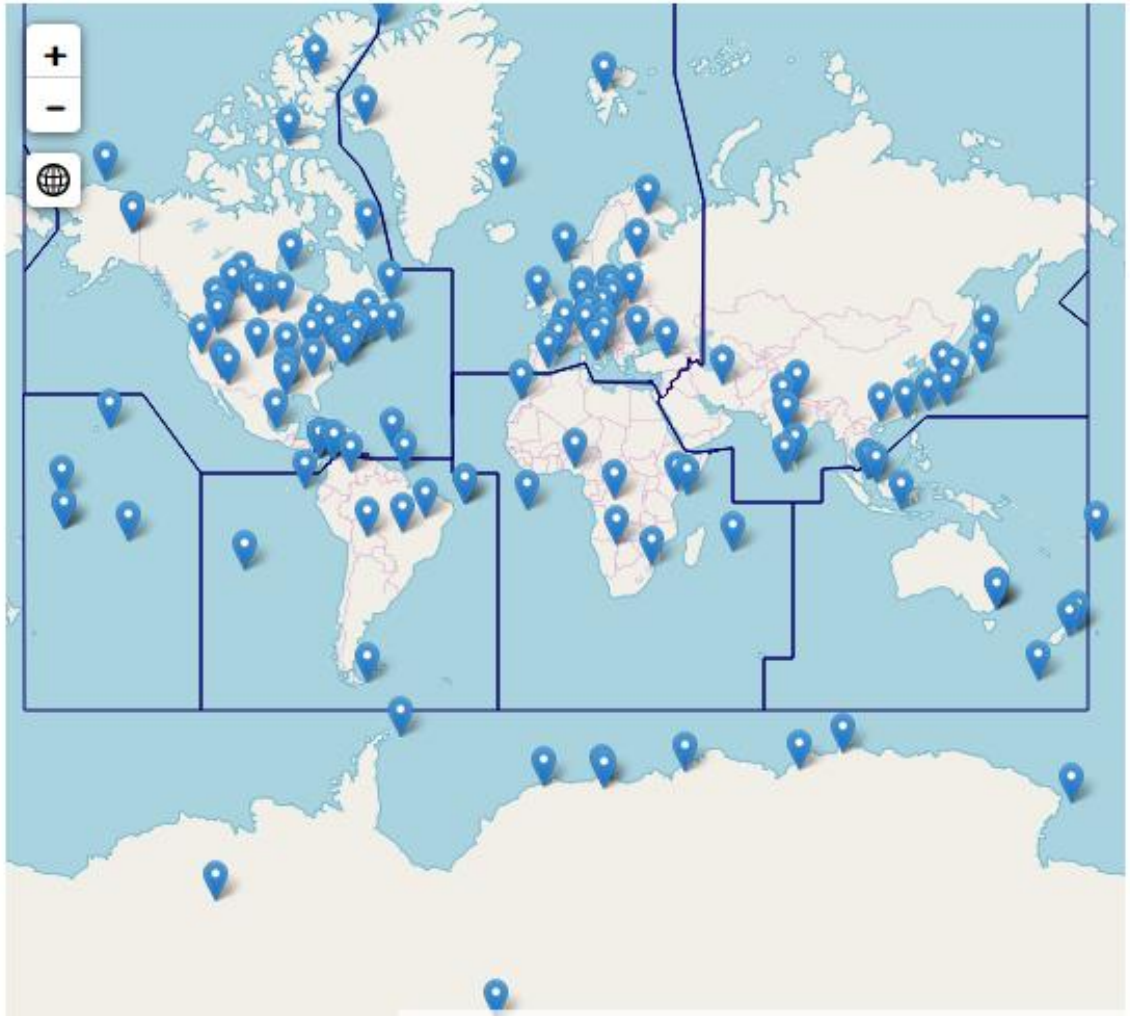
Ambiguity of Ozone Trends In the Last 2 Decades



The Tropospheric Ozone Assessment Report (TOAR) multi-satellite records show tropospheric ozone burden is changing, but disagree on the sign and magnitude.

Causes are likely sampling, algorithms, vertical sensitivity, and calibration.

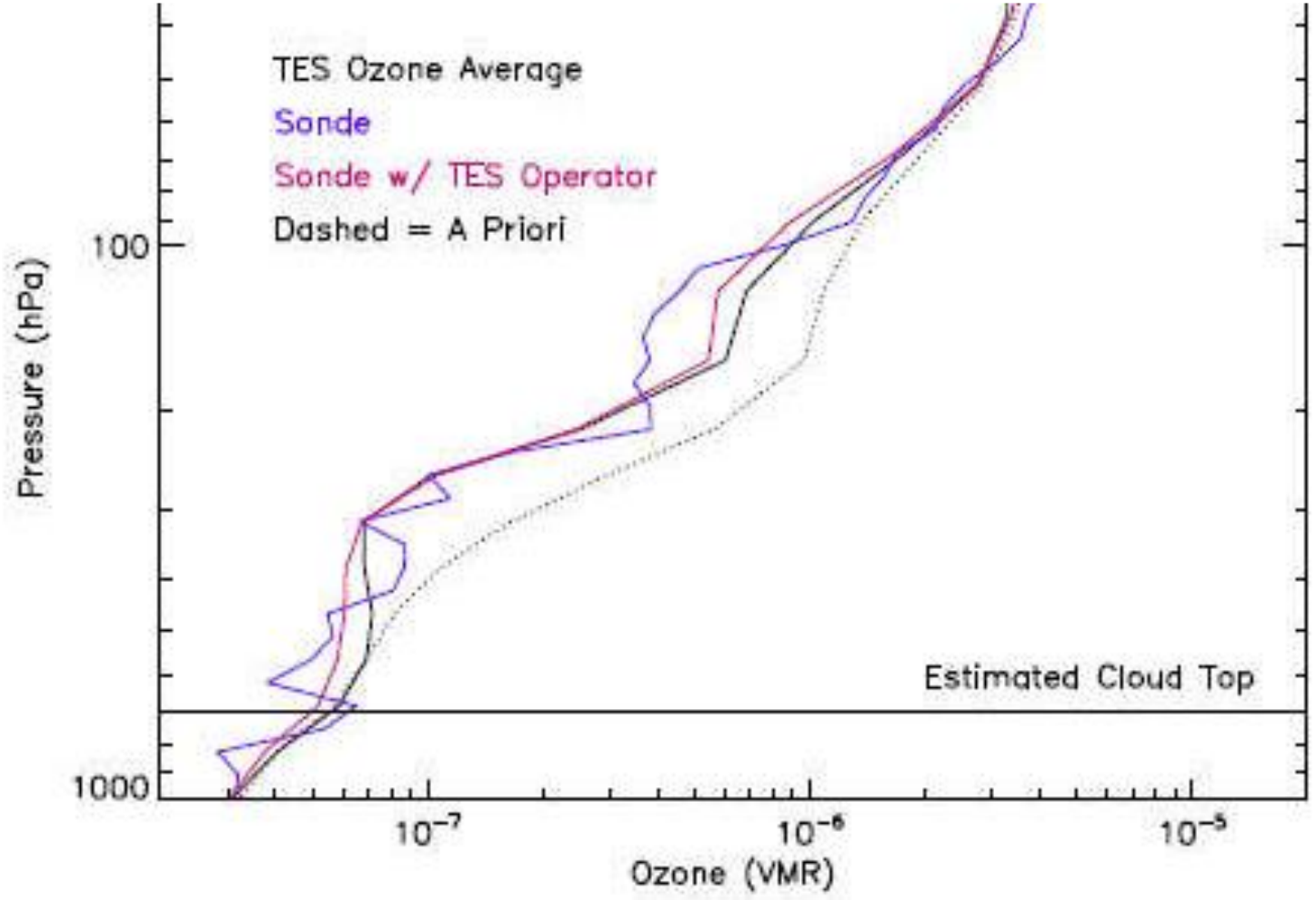
Ozone: WOUDC ozonesondes



World Ozone and Ultraviolet Radiation Data Center

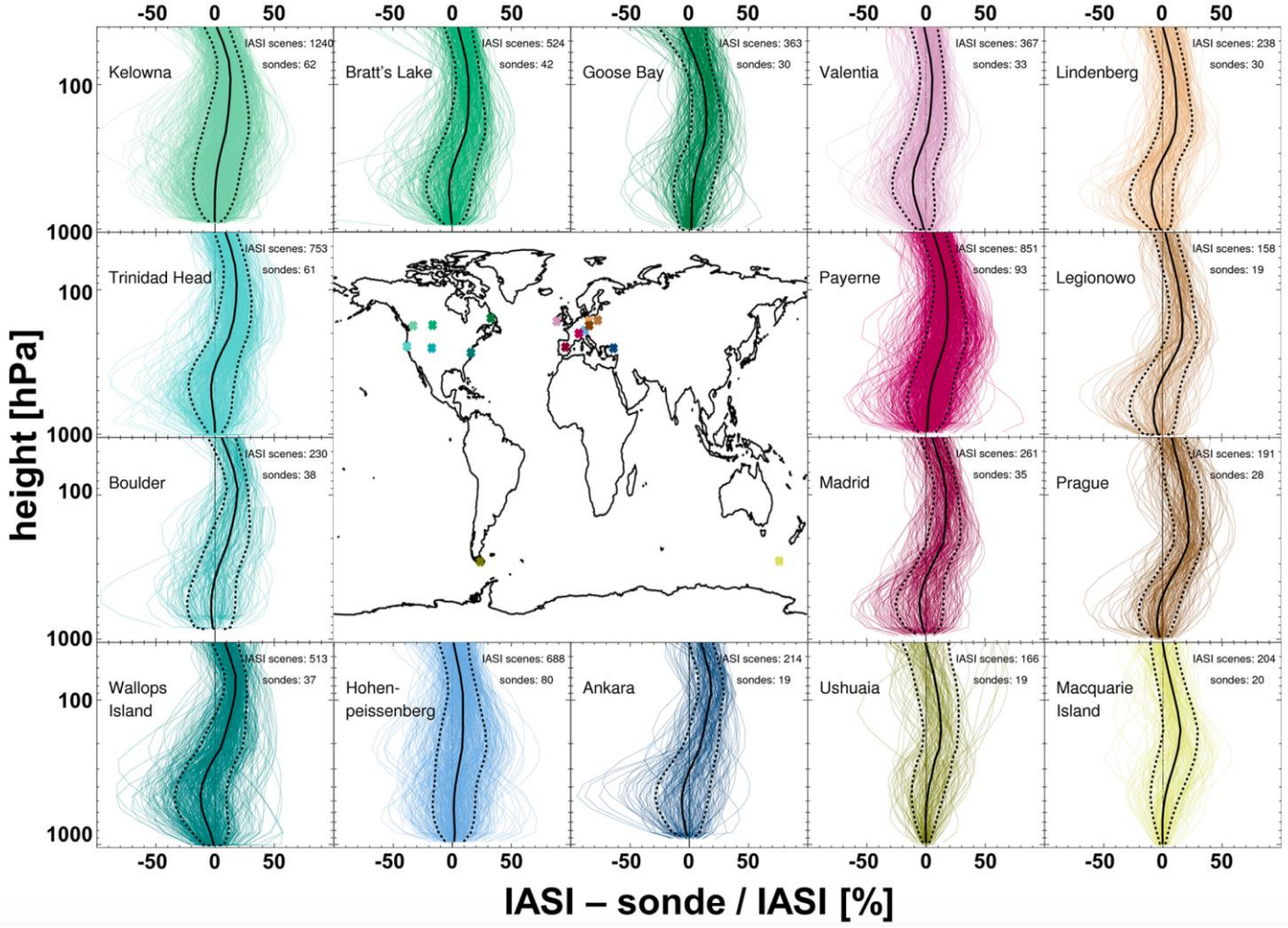
Vertical profiles of ozone starting in 1951

Sonde comparisons: TES example



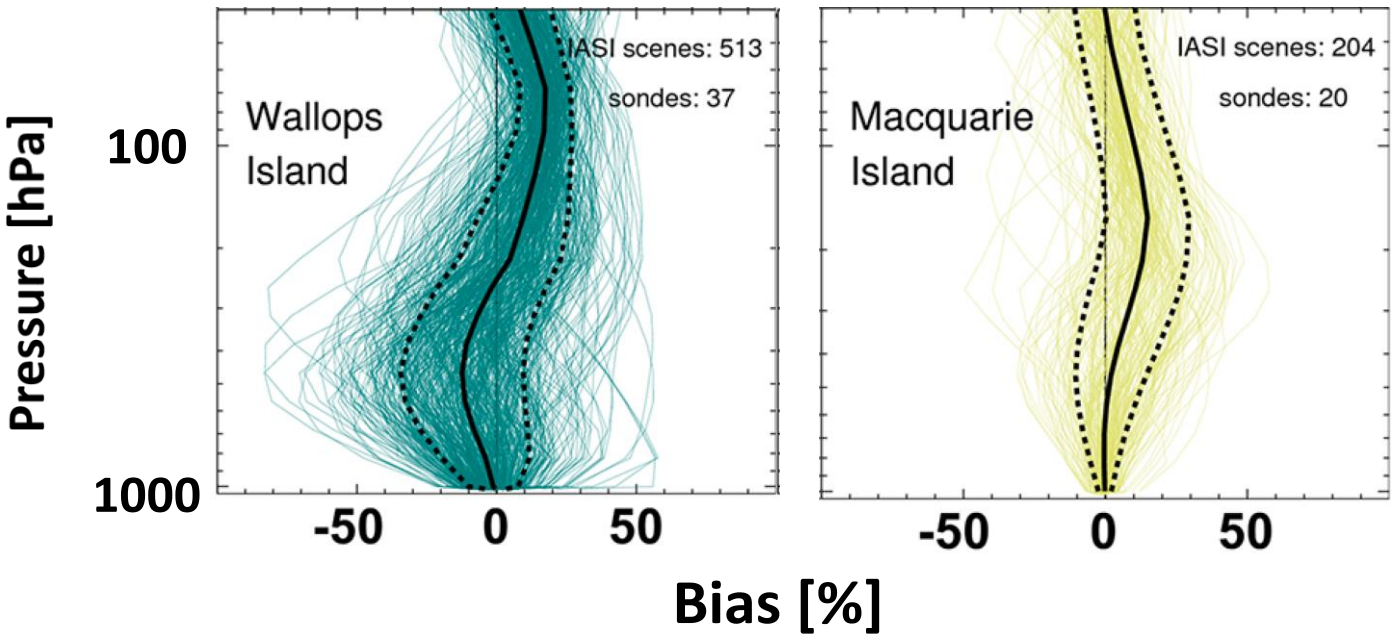
Examples of sonde comparisons (IASI)

Observation operator applied to sonde profiles for comparisons

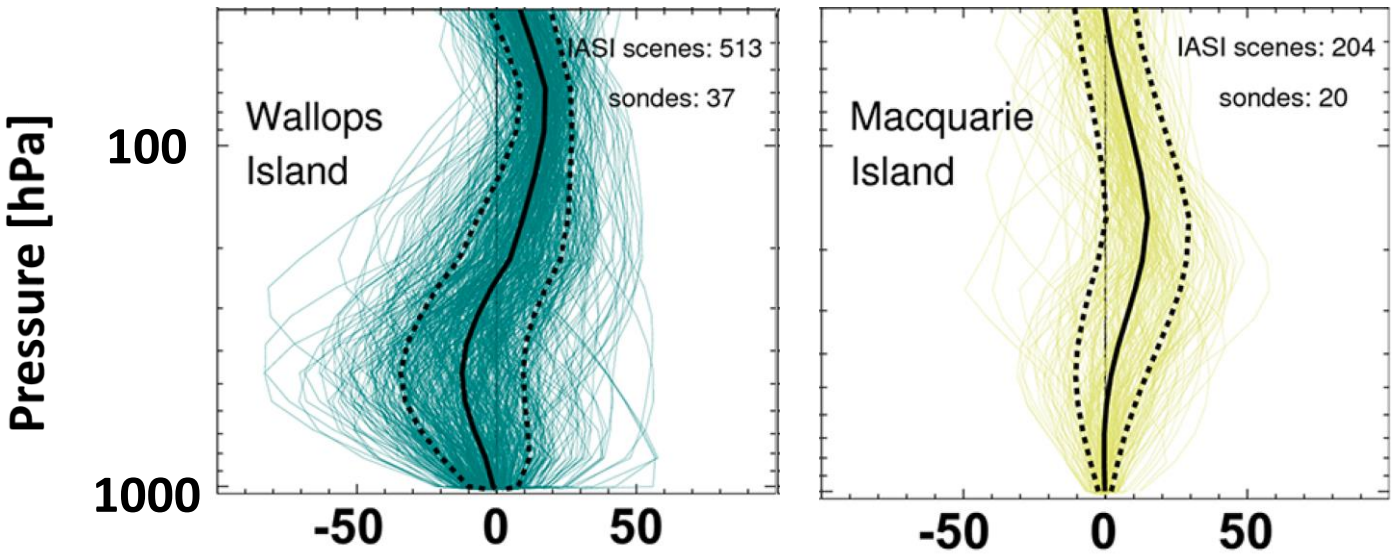


Oetjen et al., [2014]

Estimated vs actual error



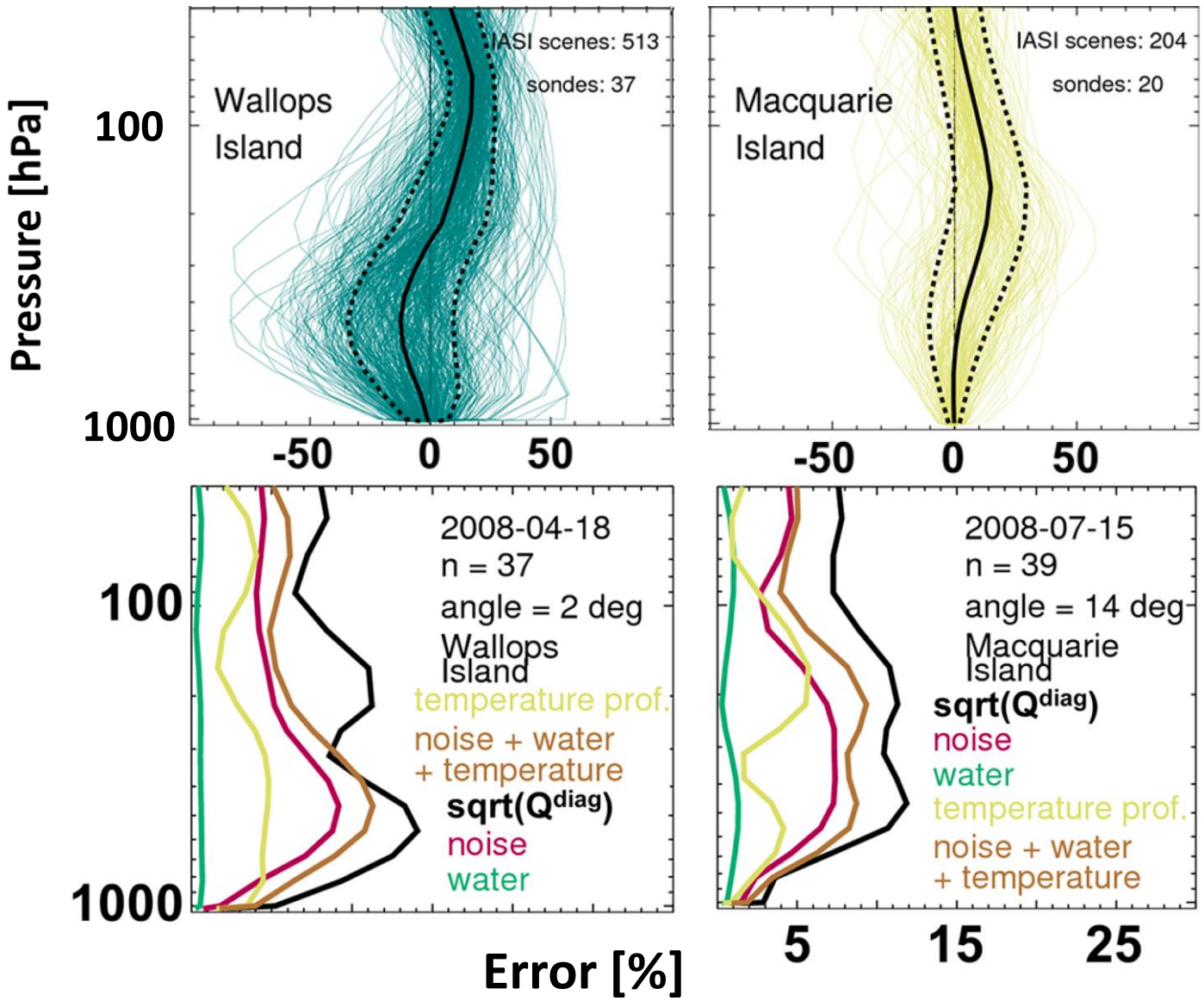
Estimated vs actual error



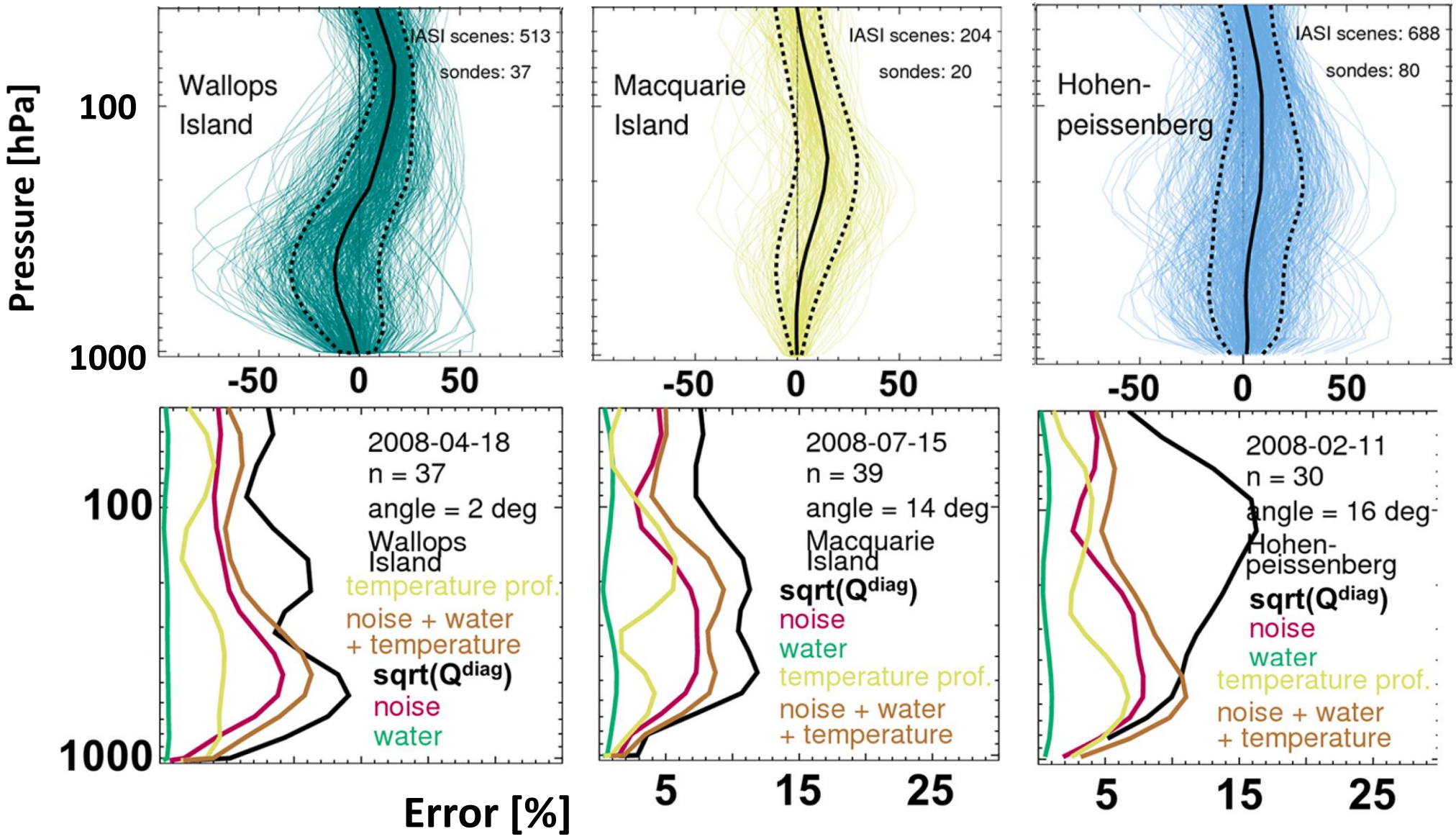
Sample error covariance:
Assume O3 does not vary.
IASI FOVs within 100 km radius, same IASI granule

$$\mathbf{Q} = \frac{1}{n-1} \sum_{i=1}^{n} \left(z_i - \overline{z}\right) \left(z_i - \overline{z}\right)^{\mathsf{T}}$$

Estimated vs actual error



Estimated vs actual error



Aircraft campaigns: HIPPO and ATom

- HIPPO data have already been used extensively for satellite validation
  - CO2, CH4, CO, N2O
- Vertical extent:
  - Up to 14 km for select cases
  - Need to make some assumption above top of measured profiles
  - Most useful for species where most of column amount lies in troposphere
- Remote:
  - Most useful for species where signal is “omnipresent” in radiances
- Coincidence criteria: Species-dependent

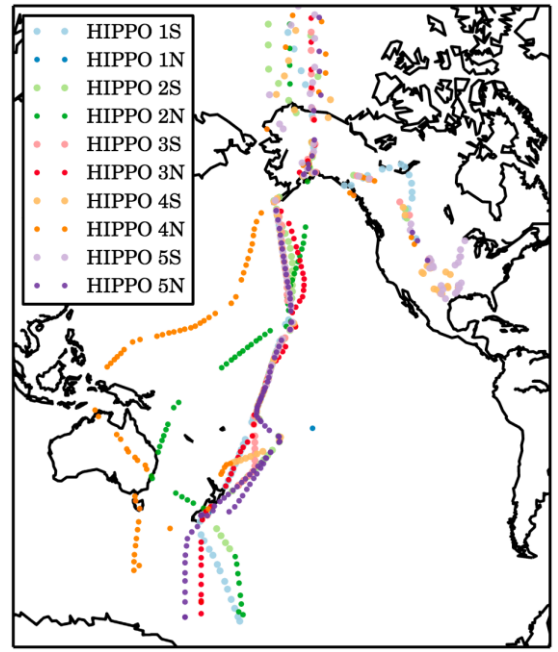


Figure: Frankenberg et al. [2016]

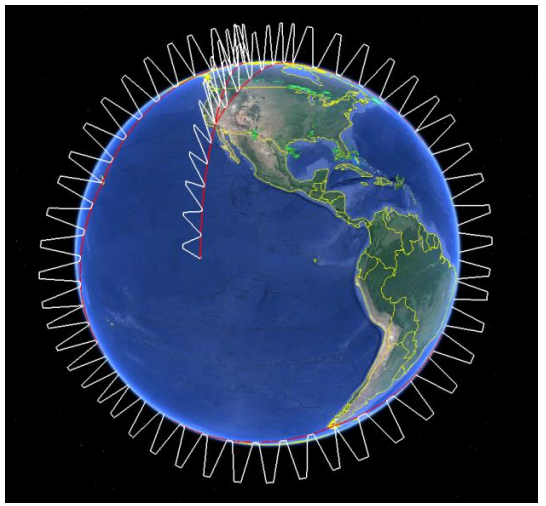


Image: https://espo.nasa.gov/at

Total Carbon Column Observing Network (TCCON)

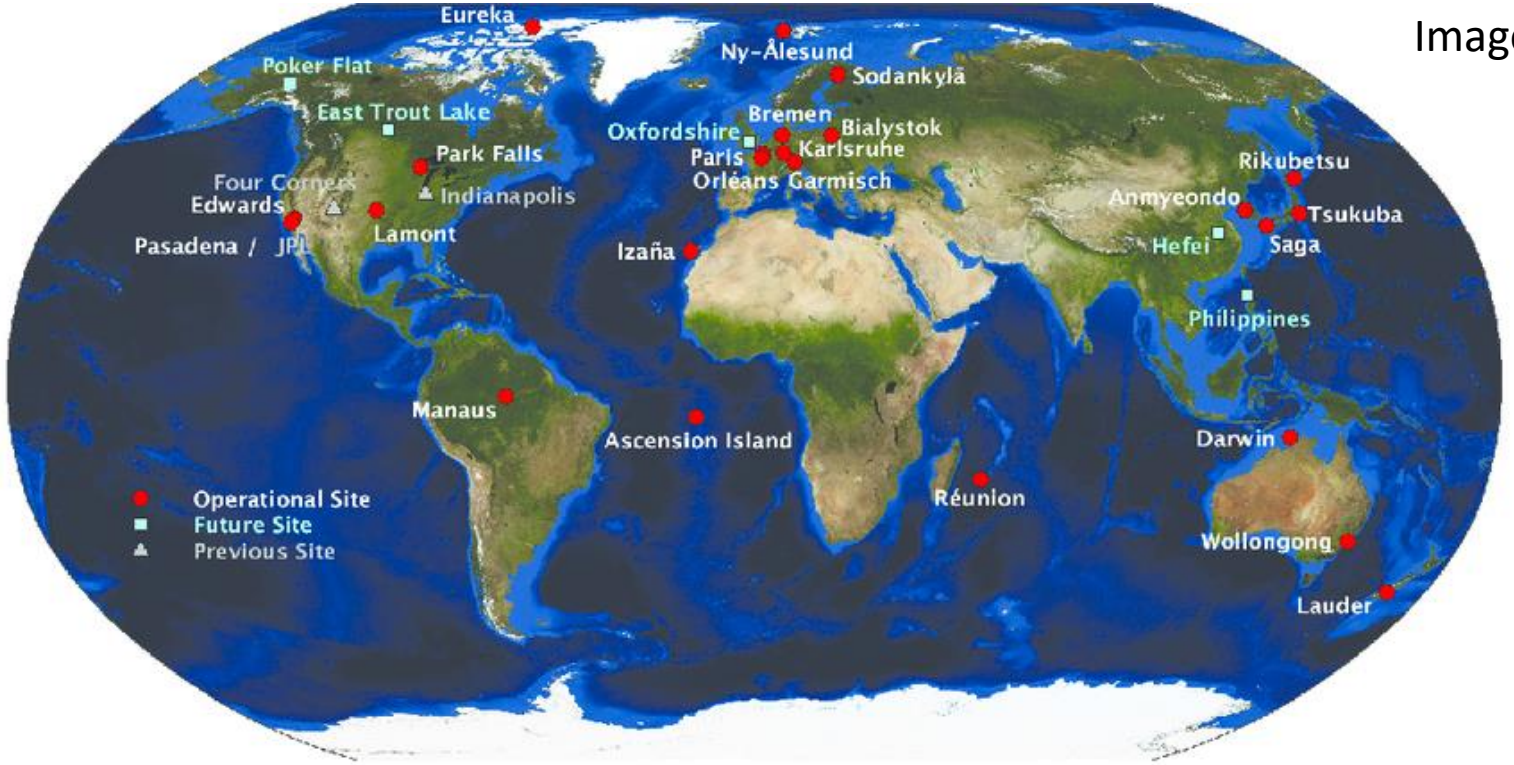
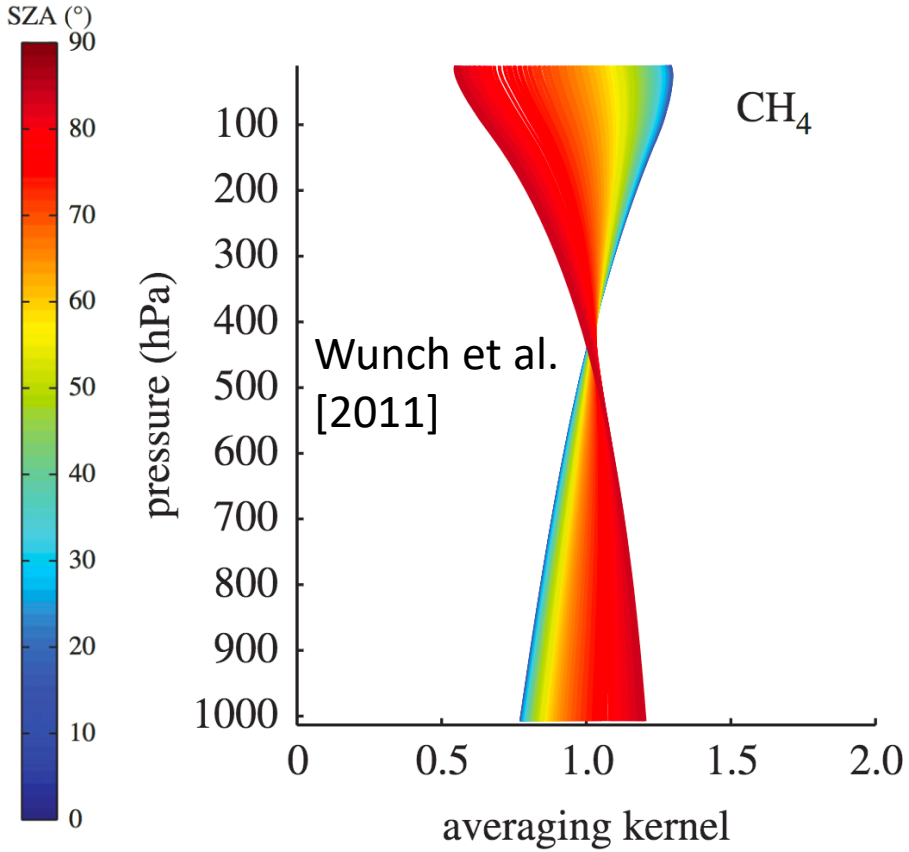


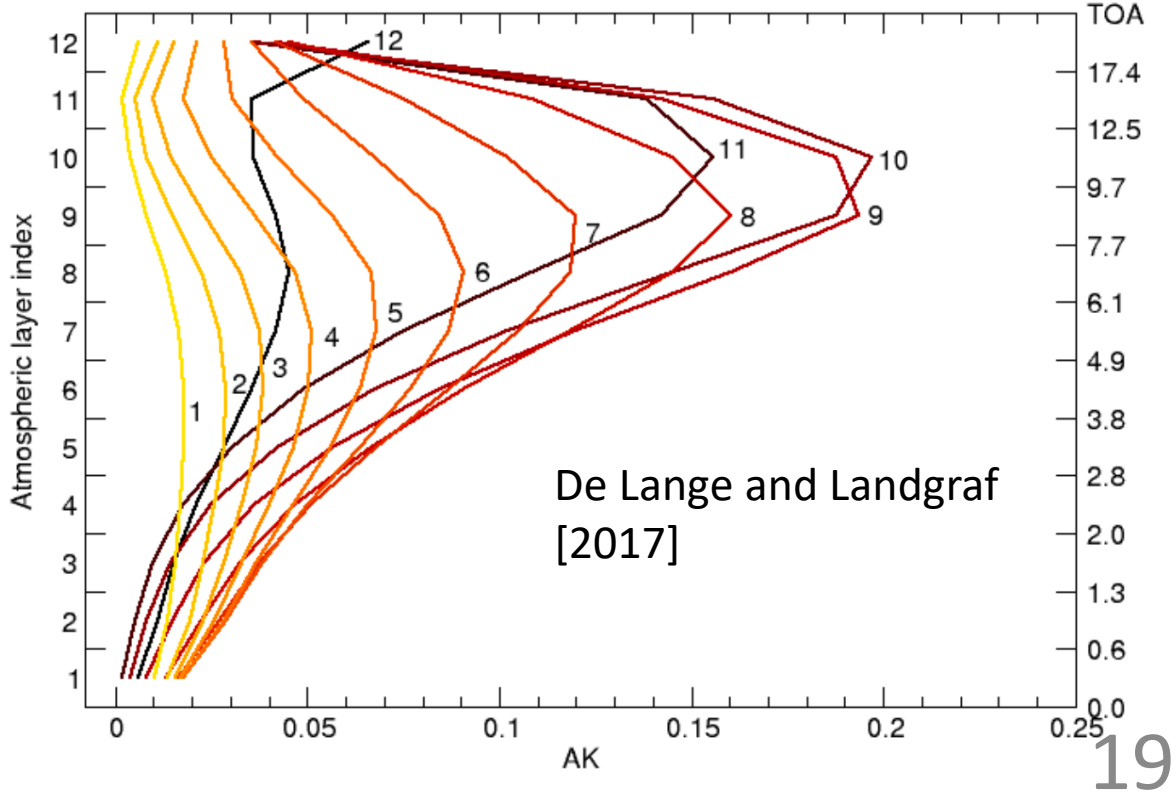
Image: Dupuy et al. [2016]

TCCON column-average products include XCO2, XHC4, XCO, XN2O, XH2O, XHDO

TCCON

- TCCON measurements are sensitive throughout the column
- IR sounders are <u>not</u>
  - Comparisons should account for differences in vertical sensitivity

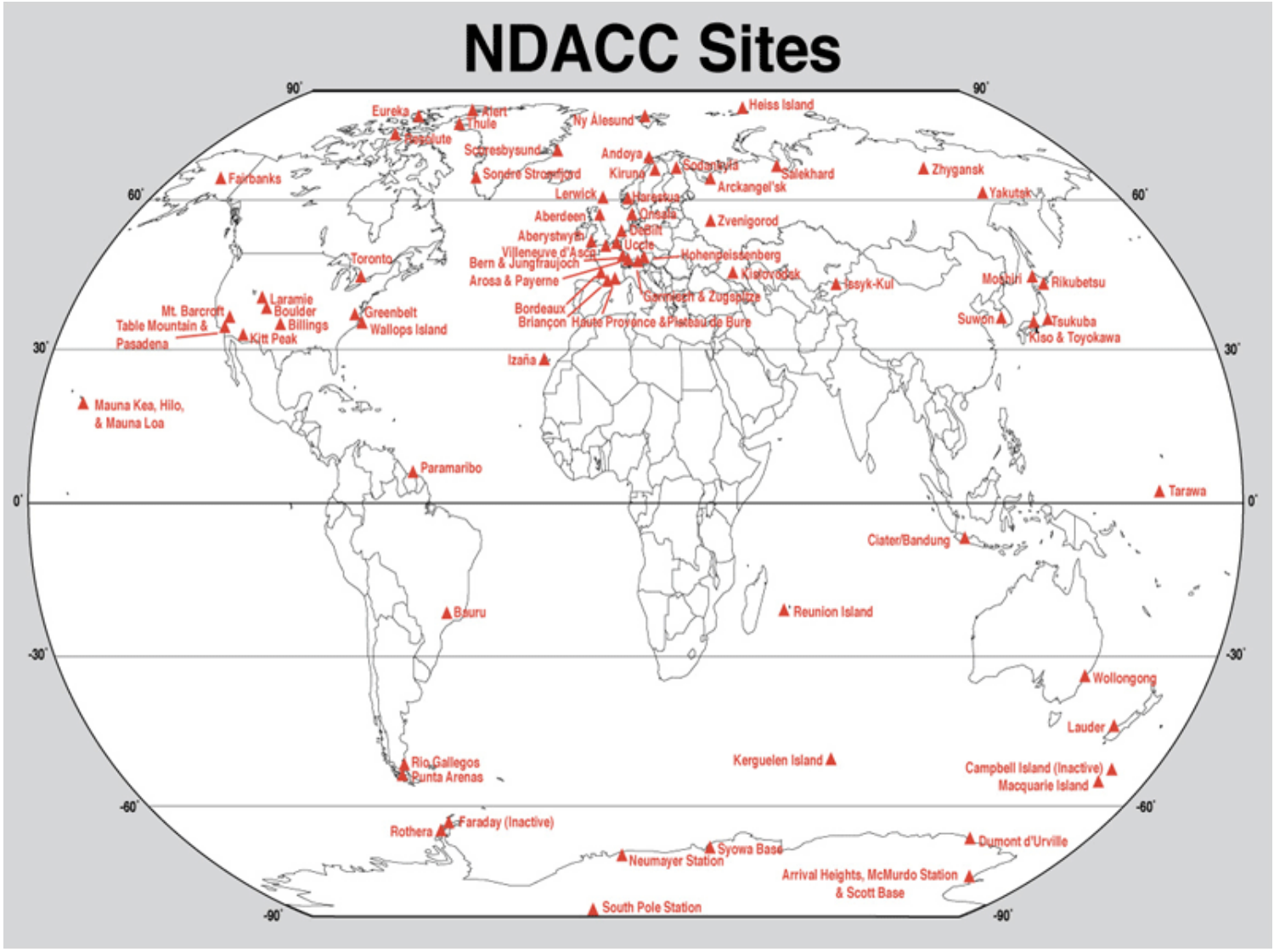




TCCON

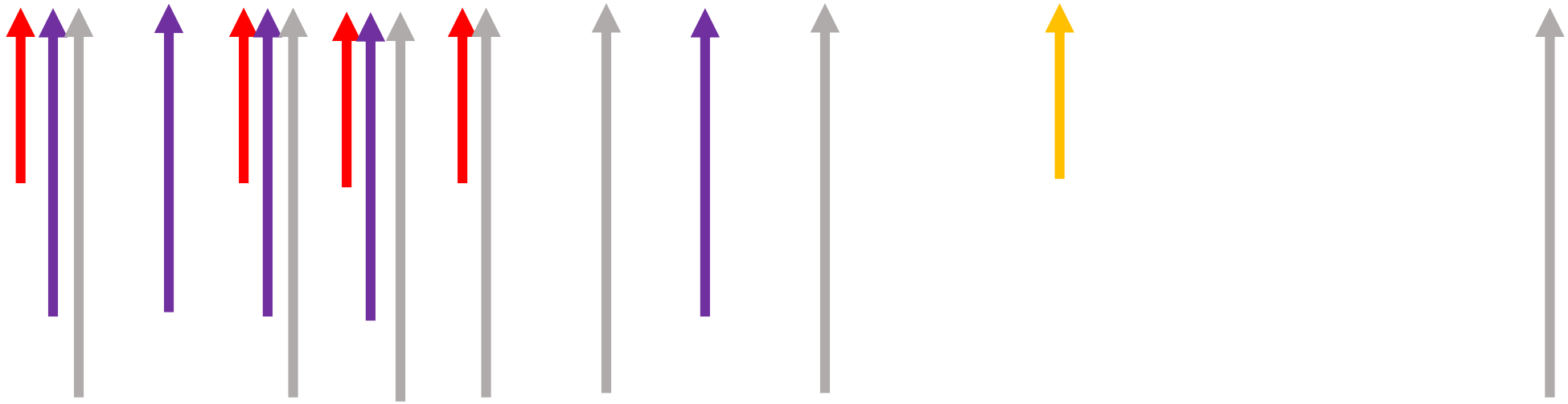
- One possible approach: De Lange and Landgraf [2017]
  - Take chemistry transport model field
  - Assume reasonable model profile shape
  - Scale model profile by TCCON column-average
  - Apply IR averaging kernel and prior to scaled model profile
  - Compare

Network for the Detection of Atmospheric Composition Change



Composition products from IR sounders (NASA portfolio)

	Omnipresent									Observable at enhanced concentrations					
Molecule	O_3	O_3 IRKs	CO	CH_4	CO_2	N_2O	HDO	HNO_3	OCS	NH_3	CH_3OH	HCOOH	PAN	SO_2	Isoprene



In AIRS v6

This composition session

CLIMCAPS-AIRS

Final thoughts

- Composition records from IR sounders can contribute to various areas in Earth System Science
- Combination of information from different measurement techniques to maximize scientific gains
  - Modeling/assimilation frameworks are key
- We need
  - Observation operators
  - To characterize spatially- and temporally- varying biases
  - To calculate errors and verify using independent datasets
  - Non-trivial!
- There are many products to evaluate.....
- Subset of sounder data
  - For evaluation of data quality, impacts of changes to L2 algorithm or L1B/L1C radiances
  - Global coverage (sub-sampled to reduce number of cases?)
  - Match-ups to reference datasets
    - Span space, time, range of atmospheric conditions
    - Examples: Ozone sondes, HIPPO, ATom, TCCON, NDACC

Back-up slides

Reference datasets

Datasets listed below could offer good value in terms of vertical, spatial, temporal coverage.

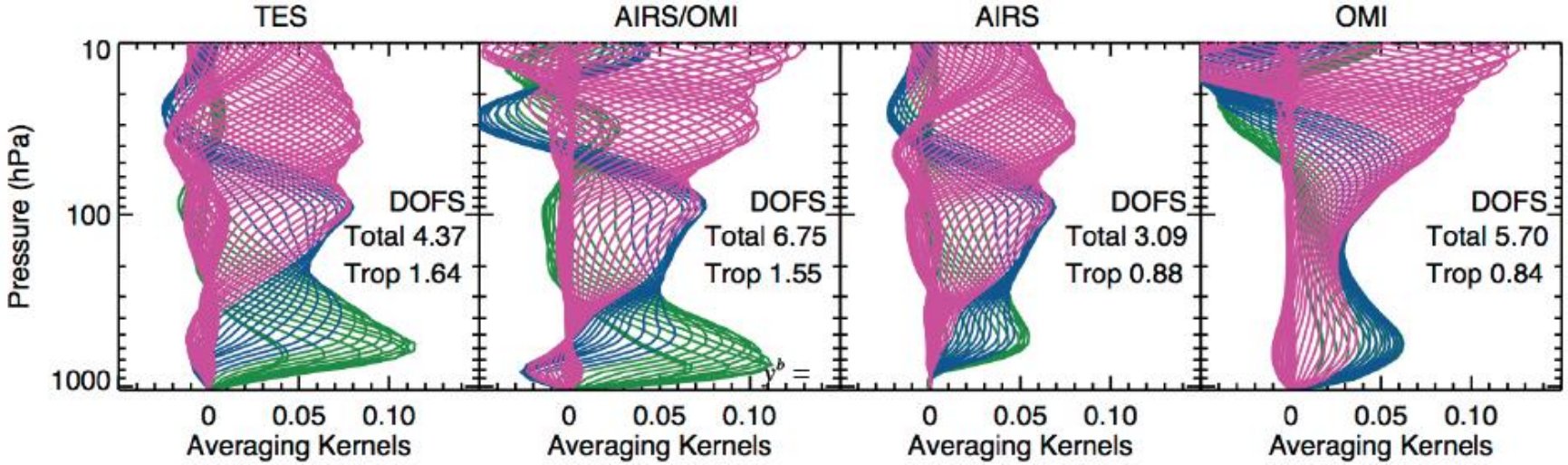
Reference dataset	Species							
	O3	CO	CH4	CO2	N2O	HDO	HNO3	NH3
WOUDC sondes	x							
HIPPO		x	x	x	x			
ATom		x	x	x	x			
TCCON		x	x	x	x	x		
NDACC		x	x			x	x	x

The table could be extended ….

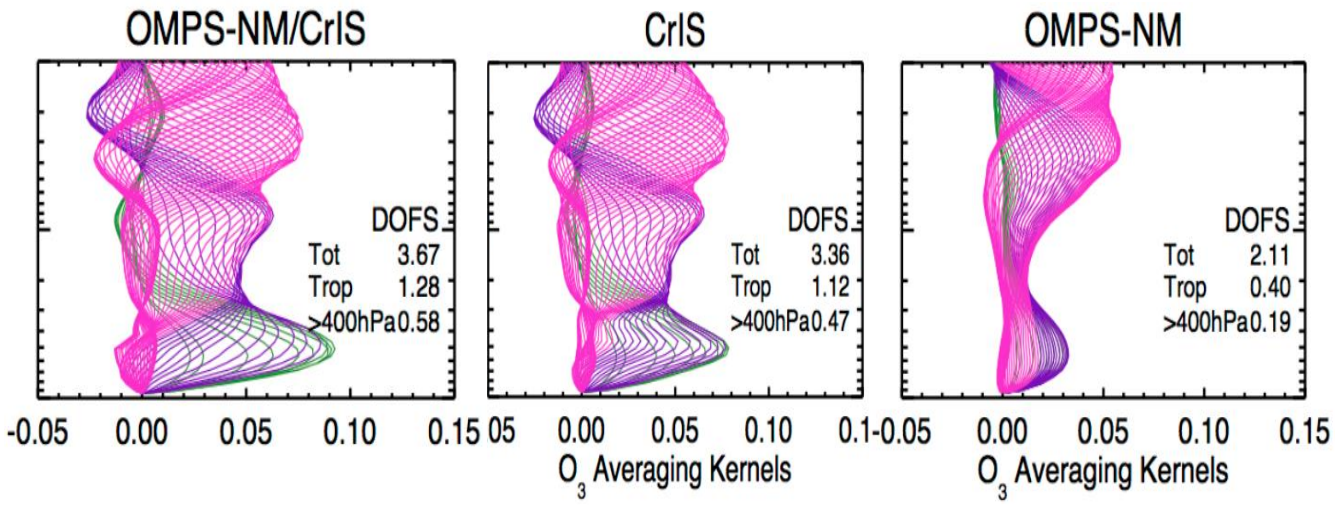
- HIPPO I :: 8 January-30 January 2009
- HIPPO II :: 31 October-22 November 2009
- HIPPO III :: 24 March-16 April 2010
- HIPPO IV :: 14 June-11 July 2011
- HIPPO V :: 9 August-9 September 2011

ATom Deployment Schedule

Deployment	Upload	Deployment	Download
ATom-1 (Summer 2016)	Jun 20 - Jul 27	Jul 28 - Aug 22	Aug 23 - 26
ATom-2 (Winter 2017)	Dec 4 - Jan 27	Jan 26 - Feb 22	Feb 23 - 25
ATom-3 (Fall 2017)	Aug 14 - Sep 27	Sep 28 - Oct 26	Oct 27 - 30
ATom-4 (Spring 2018)	Mar 12 - Apr 23	Apr 24 - May 21	May 22 - 25



Multi-spectral retrievals can offer improved sensitivity to the lower troposphere



D. Fu

- One year of IASI “clear-sky” sonde matches:
  - 110 km, 7 hours
  - ~500 matches per site
- 20,000 HIPPO matches for AIRS CH4 (all 5 campaigns)
  - Coincidence criteria: 50 km, 9 hours